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Part 1

# SHUTTLE USER ANALYSIS (STUDY 2.2)
## FINAL REPORT
## Volume II: User Charge Analysis
## Part 1: Summary

Prepared by

Advanced Mission Analysis Directorate
Advanced Orbital Systems Division

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SHUTTLE USER ANALYSIS (STUDY 2.2) FINAL REPORT

Volume II: User Charge Analysis

Part 1: Summary

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## FOREWORD

The Shuttle User Analysis (Study 2.2) Final Report is comprised of four volumes, which are titled as follows:

| | | |
|---|---|---|
| Volume I | - | Executive Summary |
| Volume II | - | User Charge Analysis |
| | | Part 1 - Summary |
| | | Part 2 - The Analysis |
| Volume III | - | Business Risk and Value of Operations In Space (BRAVO) |
| Volume IV | - | Standardized Subsystem Modules Analysis |

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# 1. INTRODUCTION

The purpose of this study was to generate alternative candidate STS flight charge approaches which will provide a basis for NASA's determination of an STS flight charge policy. The analysis used STS transportation costs furnished by NASA.

This study was needed in order for NASA to initiate the process of furnishing STS users transportation charge estimates for STS payloads. The lead time for users to plan and define new payloads or payload modifications is long, amounting to five to seven years before flight in many cases. It has been demonstrated in other studies that the transportation charges can have a significant effect on payload plans; for instance, transportation charges for payloads sharing the same flight leg can furnish incentives for multiple payload flights. Low charges for payload return will encourage payload retrieval and on-orbit payload service; thus the charge policy can provide important incentives to use the Shuttle and Spacelab. For the STS operator these incentives can help keep the STS load factors high, thus promoting efficient operation of the system. For the user the policy can encourage low-cost payload programs.

In addition to the question of charges for multiple or sharing payloads (which occur mostly on STS trips to orbit as opposed to return), and charges for payload return, the STS operator faces other new questions. The space operations with the Shuttle will be supported by man and the Shuttle can furnish services to the payload such as power, telemetry, and checkout. What charges should be made for special services and new capabilities available to the payload by the STS?

The STS User Charge Analysis was accomplished by (1) generating criteria for evaluation of alternative flight charge approaches, (2) defining alternative flight charge approaches, (3) computing flight charges for selected missions, (4) evaluating results using the criteria generated under (1), and (5) recommending flight charge approaches to be used as a basis for the formulation of a STS user flight charge policy.

During the study seven criteria were generated (see page 3-1) and 220 charge approaches were initially identified for payload transportation. As a result of all of the 220 initial approaches failing to achieve satisfactory ratings against each of the criteria, 40 additional charge approaches were identified. The evaluation of these additional charge approaches resulted in the recommendation to NASA of two candidates, a primary and an alternate. The primary candidate, which is called the composite cargo charge approach, provides for a minimum charge and a variable charge for each payload transported, with incentives for sharing and return. The rates charged can be varied to suit the projected STS traffic. The alternate charge approach, called the payload weight/size class approach, requires the computation of payload charges to each of the high-traffic orbits for each payload class (small, medium, large, and extra large).

# 2. ALTERNATIVE FLIGHT CHARGE APPROACHES

## 2.1 CHARGES FOR PAYLOAD TRANSPORTATION

Alternative flight charge approaches are described in Section 5 of Part 2 of this volume. The alternative charge approaches are shown in matrix form. The entries in the matrix describe each of the arbitrarily assigned case numbers used to identify specific analyses used in this study. The case numbers identify specific charge approaches for which payload transportation charges were calculated. For 80 of the cases (or charge approaches, as they are sometimes referred to), the charges were computed and evaluated against the criteria for the flights scheduled in 1984 in the October 1973 NASA mission model. DOD flights were excluded. Eight of the charge approaches were analyzed using 12 years of STS payload flights from this same mission model. In addition, these eight charge approaches were analyzed and evaluated using the traffic exhibited in the NASA 1972 mission model.

The basic breakdown of alternative flight charge approaches can be categorized by several primary considerations:

(1) Time period over which the flight costs are recovered

(2) Payload characteristic (i.e., weight, volume, etc.) for which transportation charges are made

(3) The choice of parameter to be used for charging for payload return

(4) The Shuttle either charges the upper stage for transportation as it would a payload or treats the upper stage as a part of the launch vehicle, transporting the upper stage free of charge in the Shuttle.

The period for cost recovery breaks down into the following alternative approaches:

(1) Recovering total transportation costs annually

(2) Recovering total transportation cost for each three-year period

(3) Recovering total transportation costs for each five-year period

(4) Recovering total transportation costs for a ten-year period.

The fourth alternative is the basis for NASA's estimate of $9.8M per Shuttle launch, which was used in the one-year analysis (1984) of the October 1973 payload mission model. However, for the 12-year analysis, the ten-year recovery period was judged to be impractical because of the uncertainties in planning that far ahead as well as the relatively large, long-term deficit funding required. The ten-year recovery period was therefore dropped from further consideration in this analysis. All alternatives were analyzed except the three-year breakeven period, which was postponed because of lack of resources. However, failure to analyze the three-year recovery period turned out to be unimportant in rating the user charge approaches.

For the purposes of this analysis, a distinction is made in the method of recovering costs between (1) recovering the average cost for each flight (called "per-flight" cost recovery), and (2) recovering costs over the entire period by the use of transportation charge rates (called "cargo" charge approach). While the first method recovered the $9.8M average cost for each flight, the second method resulted in transportation charges which varied from flight to flight in accordance with the flight manifest, but averaged out to recover all costs for a specific period (e.g., for 1984).

In the analysis of the alternative approaches to charging payloads for their transportation, the transportation charges were calculated for cases which allocated the charges according to the following payload characteristics:

(1) Payload unit ($/unit)

(2) Weight ($/lb)

(3) Volume ($/ft$^3$)

(4) Length ($/ft)

(5) Weight load factor ($/unit load factor)

(6) Payload delta energy ($/ft lb)

(7) Payload delta propellant (Tug payloads only) ($/lb of propellant increment)

(8) Cube rule weight[1] ($/lb) and destination

(9) Payload size/weight class ($/unit for each class) and destination

(10) Cube rule weight or load factor ($/unit load factor)

(11) Composite approach, combining unit charges and variable charges according to weight load factor

(12) Composite approach combining unit charges and variable charges by cube rule weight[1] load factor.

The alternatives above were applied in the analysis without a charge ceiling. In addition, alternatives (1) through (5) were applied with two types of charge ceilings: (1) no payload is charged more than the cost per flight, and (2) no user (even if the user has several payloads transported on one flight) would be charged more than the cost per flight. The description of the methods of calculation for each of these algorithms is described in Section 6 of Part 2 of this volume.

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(1) Cube rule weight is either actual payload weight (lb), or

$$\left[\frac{\text{Payload Volume (ft}^3\text{)}}{\text{STS Payload Volume Capability (ft}^3\text{)}}\right]\left[\begin{matrix}\text{STS Payload}\\ \text{Capability (lb)}\end{matrix}\right],$$

whichever is greater.

Allocation of charges to the down or return payloads was analyzed using the following approaches:

(1) Splitting the revenue between up and down payload legs (e.g., splits of 50-50, 85-15)

(2) Allocation by proportion of payload weight transported on the up leg and down leg

(3) Allocation by proportion of payload weight load factor transported on the up leg and down leg

(4) Discounting the charge rates for down payloads relative to the up payload charges.

Cases were analyzed with the Shuttle charging the upper stage (as a payload) for Shuttle transportation and also with no charges to the upper stage, i.e., the Shuttle charged only payloads for transportation.

In the initial stages of the STS User Charge Analysis, a study was made of the current practices in the transportation industry for charging for transportation. Information was obtained from the Interstate Commerce Commission (ICC), the Air Transport Association (ATA), the International Air Transport Association (IATA), the Military Airlift Command (MAC), the Civil Aeronautics Board (CAB), and several airlines with scheduled cargo transportation services or chartered service. The study of current practice for transportation charges is described in Section 2, Part 2, of this volume.

It was found that commercial cargo transportation charge policies have historically evolved from carrier-user negotiations with cognizant agency approval. There is general acceptance of the principle that revenue is based on cost plus a reasonable return with charges for transportation being based on weight of the cargo and distance transported. Many carriers prefer weight over volume charges because weight is

rapidly and easily measured; however, some carriers are concerned about the volume limitations on their cargo-carrying vehicles and make extensive use of the cube rule. The best example of this is aircraft. The cube rule is a charge option in which the transportation charge is applied by payload weight or payload volume, whichever is the greater percentage of the vehicle capability. It was found in commercial practice that the cube rule is applied using densities (in terms of $lb/ft^3$) which are based on historical practice rather than the current capability of the vehicles. For instance, one source mentioned that the $110.5\ kg/m^3$ ($6.9\ lb/ft^3$) value, which has been in common use for many years, was based on the design capability of box cars in the World War I time frame. General acceptance is also noted for a minimum charge, which usually is based on the weight associated with one cubic foot according to the cube rule, for any shipment. There is also general acceptance for special rates for special commodities or classes of cargo.

Commercial cargo charge policies and practices which have some degree of applicability to STS are:

(1) Revenue based on cost plus a reasonable return

(2) Charges by cargo weight

(3) The cube rule modified to be applicable to the STS

(4) Minimum charges, again modified to be applicable to the STS

(5) Rate charges for special commodities or classes of cargo

(6) Fixed rates analogous to those used by IATA

(7) An industrial fund approach similar to that used by MAC

(8) Incentives for high load factor including reduced costs for larger-weight payloads and incentives for return leg (inbound) payload traffic similar to the MAC incentive.

(9) The policy of limiting liability of the carrier with respect to the cargo carried.

## 2.2 PARAMETERS CONSIDERED FOR POTENTIAL "ADD-ON" CHARGES

A number of parameters were considered in the study as potential add-on charges for payload transportation. Some parameters, such as payload volume and minimum charges, were found to be so important that their effects are included in the basic transportation charge approaches recommended. Other parameters, such as Orbiter occupancy time, priority flights, use of ancillary equipment, and STS flight crew, are recommended for further study by NASA as add-on charges. It is recommended that piggyback payloads be covered by a special category which needs specific definition but which is compatible with the criteria. Token transportation charges would be made at NASA's discretion for this special category of payloads.

### 2.2.1 Special Payload Integration Charges

In order to meet the "simple to administer" criterion (see Section 3), the number of "add-on" charges should be minimized. For instance, charges for special payload integration costs need not be another special charge. The equipment required should be included in the ancillary equipment add-on charge and any excessive Orbiter occupancy time incurred should be included in that category of add-on charges. It is recommended that every effort should be made to minimize the number of payloads requiring special integration operations if these operations are going to incur additional charges, i.e., increase the cost per flight. One case where special integration efforts may be legitimately involved is the installation and checkout of radioactive power sources because of safety considerations.

In general, normal integration costs should be included in the STS operations costs to avoid the necessity to bill payload programs for a series of "add-on" charges; this approach would avoid the poor public relations image created by these add-ons. Where an abormal integrating effort is required, as for RTGs or other potentially hazardous payloads, the payload program would probably accept a special negotiated surcharge. If special equipment is needed to perform the integration effort, labor charges might be buried in the equipment costs to simplify the charge procedure. Such an approach would satisfy the fair share criterion and recover costs without violating any other criteria designed to stimulate efficient payload operations on the STS.

Multi-payload operations should be encouraged either by not charging extra if additional integration efforts are involved, or else by keeping the costs low. Perhaps the ability to reduce flight costs for each payload through multiple payload launches will allow any extra integration costs to be factored back into the transportation costs while holding launch costs to a low enough level to encourage multiple launches.

### 2.2.2 Ancillary Equipment Charges

In general, payloads flown on the STS will require some ancillary equipment to support the flight. This equipment may be needed to integrate the payload into the STS, to check out the payload on orbit, or to provide for orbital services which would reduce the cost of overall payload operations. A given payload may require equipment which can be used by most of the other payloads, or it may need specialized equipment peculiar to only that payload or a very small number of payloads. The approach to charging could be different for the generalized and specialized equipment.

Some typical types of ancillary equipment are listed below as generalized or specialized equipment.

| Generalized Equipment | Specialized Equipment |
|---|---|
| On-orbit checkout equipment | RTG checkout equipment |
| Shrouds (plastic bag type) | Purge gas diffusers |
| Single point grounding kit for EMC | GSE for prelaunch checkout |
| Shock mounting | Shrouds (rigid, P/L-peculiar) |
| Retrieval and docking mechanisms | Software for on-orbit checkout |
| Servicing equipment | |

Possible charge approaches for generalized equipment include:

(1) Include development and direct costs in basic transportation charge or in STS operations cost

(2) Add-on charge for recovering recurring costs

(3) Add-on charge for recovering recurring costs and prorated portion of non-recurring costs.

Possible charge approaches for specialized equipment include:

(1) Prorate development costs among users; charge direct costs to user on per-flight basis which would be included in operations costs for the flight.

2.2.2.1 Charges for Generalized Equipment

1. Charge portion of development cost (based on number of potential user programs) to each user program on a one-time basis only. Add direct costs per flight (may be portion of unit cost).

2. Charge each flight of any payload a cost for each item of equipment that covers both non-recurring and recurring costs. For (1) and (2), sum all items to get total cost for generalized equipment.

3. Use a flat charge for 1 to $n_i$ items, a higher flat charge for $n_i + 1$ to $n_j$ items, and a third flat charge for $n_j + 1$ to $n_k$ items.

4. Use a fixed flat charge regardless of number of items of generalized equipment

The second charge approach is the simplest and fairest. The first charge approach is less simple but fair. The third and fourth approaches are simple but less fair.

A multi-payload adapter/dispenser might be provided free to encourage high load factors. Care should be taken to avoid costs for ancillary equipment which could cause the STS to be more expensive than expendable launch vehicles.

2.2.2.2 Charges for Specialized Equipment

1. Charge each flight for all non-recurring and recurring equipment costs. Sum specialized equipment costs for total specialized equipment costs.

The total equipment charge is the sum of charges for generalized and specialized equipment.

2.2.3 Charges for STS Flight Crew In Excess of Normal Complement

The Space Shuttle currently has provisions for a four-man crew in its normal operating mode. The Shuttle can accommodate up to ten persons, if necessary. Since a four-man crew should normally be able to handle payload operations, it must be assumed that the additional personnel are necessary to support payload operations in some manner, e.g., perform experiments; therefore, it seems reasonable for the additional personnel and their provisions to be charged against the payload.

Possible charging options for these additional weights are:

(1) Transportation charge plus special integration charges if special integration problems exist and are chargeable. The personnel, equipment, and provision weight beyond the normal 28 man-days would thus be chargeable.

(2) An EVA surcharge if EVA is required.

(3) Sortie surcharges instead of (1) or (2).

All of these charge policies would help to recover costs, ensure that the user pays a fair share of the transportation costs, and be relatively simple to administer. It does not appear that the remaining four charge criteria, i.e., provide incentive for payload effects and high load factors; be insensitive to mission model changes; and be competitive with expendable launch vehicle costs, apply for crew charges.

### 2.2.4 Summary

Table 2-1 summarizes the parameters studied with potential for add-on charges and the recommendations resulting from the study.

Table 2-1. Additional Parameters Analyzed for Possibie Inclusion in Charging Formula

| Parameter | Recommendation |
|---|---|
| 1. Volume and length of payload | 1. Apply the cube rule to recover costs for low-density payloads. |
| 2. Separate charging category for Shutt'e and Shuttle-Tug flights | 2. Expendable upper stage problem needs more study. Recommend charging the upper stage as Shuttle payload. |
| 3. Propellant utilization or destination, Tug only | 3. Load factor charge approach fits evaluation criteria better than propellant charge approach. |
| 4. Orbiter occupancy time | 4. Needs study for specific missions. Crew standby expense is small compared to expended elements of STS and Orbiter turnaround costs. |
| 5. Priority flights (both high and low) | 5. Recommend study of high-priority flights for planetary launches. Charges should correspond to round trip full-load STS charge (load factor 1.0 up and 1.0 down on Shuttle, 1.0 round trip on Tug). Retrieval and return of payloads can be low-priority and discount rates are recommended. |

Table 2-1. Additional Parameters Analyzed for Possible Inclusion in Charging Formula (Cont'd)

| Parameter | Recommendation |
|---|---|
| 6. Use of ancillary equipment | 6. Numerous charge options for general-purpose equipment. Needs study. |
| 7. STS flight crew (above basic complement) | 7. Primary approaches are:<br>(1) Charge for transportation and special integration, or<br>(2) Surcharge for sortie flights. |
| 8. Special payload integration costs | 8. Charge for special equipment or Shuttle occupancy if appropriate. Require integration testing to minimize the STS costs. Negotiate special cases. |
| 9. Piggyback payloads | 9. Recommend policy providing for token transportation charges at NASA's discretion. |
| 10. Minimum charges | 10. Minimum charges for payload transportation are needed the first five years of STS operation, optional thereafter. |

## 3. CRITERIA AND EVALUATIVE TECHNIQUE

The criteria used to evaluate the alternative charge approaches are listed below.

(1) Recover at least $9.8M x total number of Shuttle flights in October 1973 mission model.

(2) Policy should contain incentives for payload effects implementation. Return payload charge should be competitive with new payload.

(3) Policy should provide incentives for high load factor operations.

(4) Policy should be insensitive to mission model changes.

(5) Individual user sharing a flight must be charged a fair share of total cost.

(6) Charge rates must be competitive with expendable launch vehicles.

(7) Simple to administer.

These criteria were ranked in order of importance and assigned weighted value in terms of point ratings out of 100 for each of the seven criteria.

The point ratings used to weight the importance of each of the criteria are shown in Table 3-1.

Each of the charge approaches (cases) analyzed was rated against the criteria using the weighting factors and assigned points in accordance with the resulting charges. In order to assign these points, each criterion was broken down into specific desirable features which,

Table 3-1. User Charge Analysis Ranking and Weighting of Criteria

| Rank | Criterion | Weighting | Rationale |
|---|---|---|---|
| 1. | Recovers Costs | 24 | Commercial exploitation of space should recover transportation costs |
| 2. | Payload Effects Incentive | 21 | Lower costs, particularly lower initial costs with refurbished payload hardware and standard hardware replacing new custom hardware makes the market more attractive and encourages new users. |
| 3. | High Load Factor Incentive | 16 | High transportation efficiency is obtained with high load factor. Average transportation cost per user is reduced. |
| 4. | Insensitive to Mission Model | 14 | Minimize charges to charge policy; however, some adjustments should be acceptable with time, since rates change inevitably. |
| 5. | Fair Share | 13 | Important to user, policies should be reasonable, defendable and relatable to current practice when possible. |
| 6. | Competitive with Expendable Launch Vehicle | 7 | Initial criterion for user acceptance of STS. Long-term acceptance depends on other criteria and should be rated higher than this initial acceptance criterion. |
| 7. | Simple to Administer | 5 | Policies need to be simple to avoid confusion, red tape and expensive administration. Individually-negotiated transportation charge is not considered in this analysis. |
| | Total | 100 | |

if exhibited by the charges, would result in the addition of the assigned points to the point total for that charge approach. For instance, the 21 points for payload effects incentive were split up so that five points were assigned for low-cost payload effects and hardware standardization and 16 points were assigned for payload return incentive. The economic value of on-orbit maintenance also depends, to some degree, on the return of the failed spacecraft elements and the module exchange mechanism. Weight and volume increases in payloads are required in order to apply low-cost design principles and utilize standardized hardware; however, this is less important than payload return incentive and consequently is assigned the five points.

The 16 points available for payload return incentive were prorated so that if a returning spacecraft saved 50 percent or more of the spacecraft unit cost by returning the spacecraft and refurbishing it instead of procurring a new spacecraft, all 16 points were allocated to the charge approach. If the percentage was 25 percent to 50 percent, eight points were assigned and if the average spacecraft savings for reuse was zero to 25 percent, no points were assigned. Similarly, the other criteria were broken down as described in Part 2 of this volume.

The point ratings resulting from these evaluations for each charge approach were used in the analysis to obtain evaluative rankings between the alternative payload approaches. These rankings are displayed in Section 7 of Part 2 of this volume.

Ratings were also used to evaluate each charge approach from the point of view that it is desirable that the recommended charge approach be rated as satisfactory against each of the criteria in addition to having a high rating relative to all criteria. In order to accomplish this, acceptable lower bounds for each rating were derived and are displayed in Section 7, Part 2, of this volume.

## 4. TRANSPORTATION CHARGES AND CHARGE RATES

The transportation charges resulting from applying the charge approaches to mission model traffic are described in Section 6 of Part 2 of this volume. The data from these analyses are on file at NASA and The Aerospace Corporation.

As discussed in Section 5 of this document, the results of the quick-look cargo charge analysis completed in early April 1974 indicated that the following features of the charge approach showed merit relative to the criteria for selecting a charge approach:

(1) Charges in proportion to the payload load factor

(2) A discount for a payload which shares a flight leg

(3) Return payload transportation charges at a reduced rate

(4) Some type of a unit payload charge which could be applied as a minimum charge for each satellite or each payload transported

(5) Shuttle transportation charges for the upper stage.

The composite approach for cargo charges combines the best features of the cargo charge approaches investigated in the quick-look analysis.

The generalized formula for the composite approach is:

$$\text{Shuttle Transportation Charge for Payload X} = \left[\begin{matrix}\text{Minimum} \\ \text{Charge}\end{matrix} + \begin{matrix}\text{Variable} \\ \text{Charge}\end{matrix}\right]\left[\begin{matrix}\text{Discount} \\ \text{Factors}\end{matrix}\right] = \left[M + C_1 \times L_s\right]\left[\begin{matrix}\text{Discount} \\ \text{Factors}\end{matrix}\right]$$

where:

$M$ = Minimum charge

$C_1$ = Charge rate for variable charge in the units of \$/Shuttle weight load factor

$L_s$ = Shuttle weight load factor for payload X.

The minimum charge is not applied to an upper stage with payload attached since the payload is already paying the minimum charge and an additional minimum charge for the upper stage would be paid for by the upper stage payload, in effect charging more than one minimum charge to that payload.

The formula for Tug transportation charge is similar but contains no additional minimum charge over that charged by the Shuttle. Tug transportation by the Shuttle is recovered as well as the cost of operating the Tug.

The basic transportation charge without discount applies to single payloads transported from the surface of the earth to orbit without sharing the STS with other payloads. In the composite approach, discounts are to be considered for payloads sharing an up flight (up flight leg) or sharing a down flight. Discounts also are to be considered for return payloads, whether sharing the return flight leg or not.

Typical transportation charges resulting from an analysis of the October 1973 mission model are shown in Figure 4-1. The figure displays typical payload charges for any up payload transported in the Shuttle in the 1980-1984 time period. Payloads requiring an upper stage have a higher charge rate not shown on this figure. The minimum charge applicable to a payload transported alone in this example is \$4M. The variable charge for a payload transported alone is \$5M per unit payload load factor. This charge rate increases the Shuttle transportation charge as the payload load factor increases (see Figure 4-1). The payload load factor for this case is based on payload weight load factor or payload volume load factor, whichever is greater. The payload sharing discount rate is 20 percent and is applied when there are multiple payloads on, in this case, the up payload flight leg. Not shown on this figure are the return payload rates which would be reduced by 60 percent for Shuttle transportation. It should be noted that a 14,500 kg (32,000 lb) payload will have a load factor of one on a return trip; however, on the up trip the payload load factor would be

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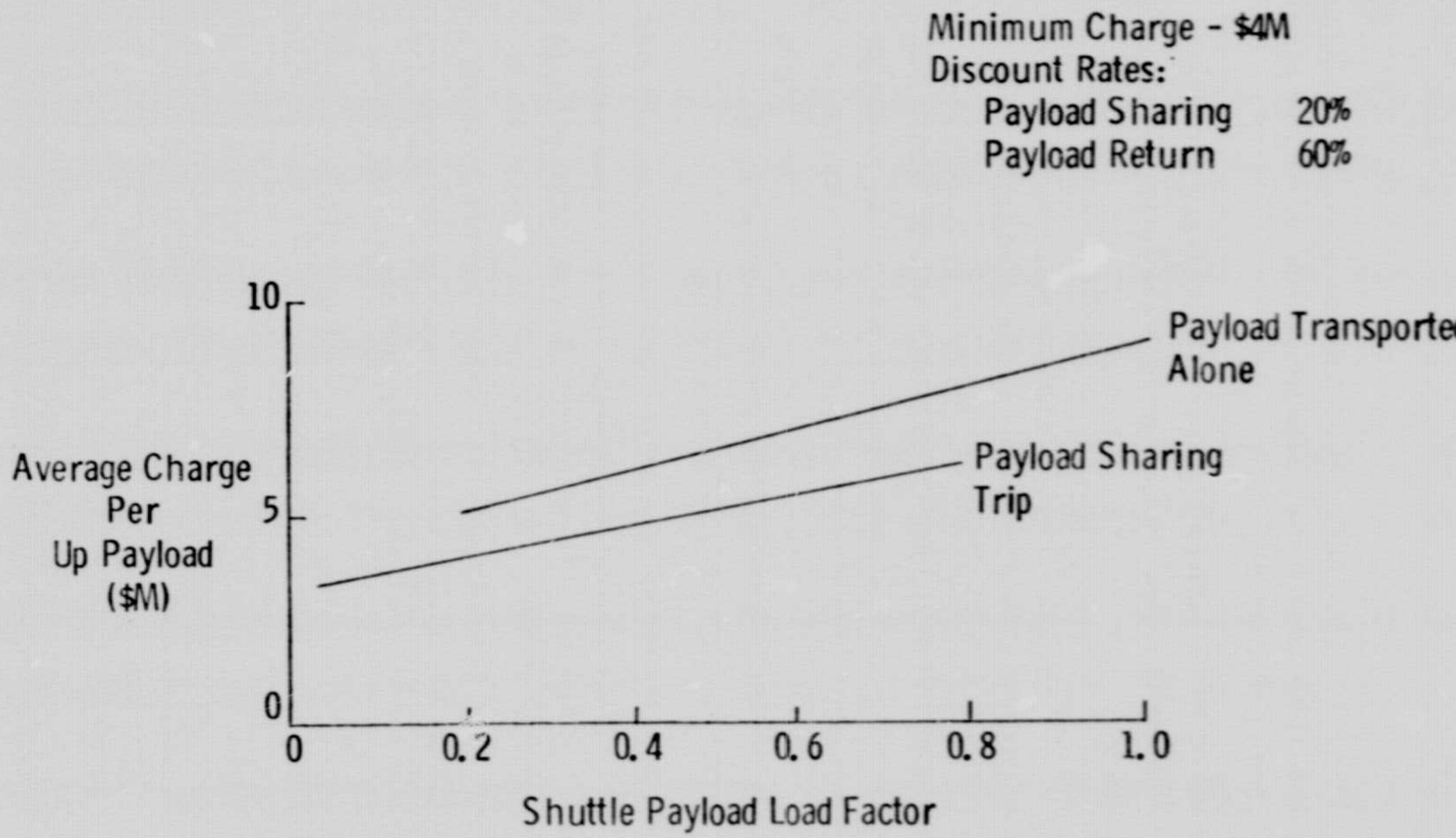


Figure 4-1. Example Transportation Charges for Up Payload Trip On Shuttle, Composite Cargo Charge Approach, Recover Costs For 1980-1984

considerably less than one depending on the destination since the capability of the Shuttle for up payload trips would normally be between 18,000 kg (40,000 lb) and 29,500 kg (65,000 lb).

Other examples of payload transportation charges resulting in application of a composite cargo charge approach are shown in Section 6 of Part 2 of this volume.

One of the alternative charge approaches recommended for further consideration provides for transportation charges according to payload weight/size class for each of the five high-traffic destinations. The payloads are divided into four classes: small, medium, large, and extra large. The small and medium size payloads have a high probability of sharing on multiple payload flights on the Shuttle or Tug. Large and extra large payload size classes seldom share in multiple payload flights. Therefore, discounts for sharing are applied to the small and medium size payloads but not for the large and extra large sizes.

The charge rates for each of the five destinations are adjusted to recover costs of STS flights to that destination. The five destinations are noted on Figures 4-2 and 4-3. These figures show the payload charges for each of the four payload classes. The lowest charge in each case is for the small payload class and charges are increased upward by steps in accordance with the payload weight load factor range of each class of payload. Charge rates for return flights are one-half the charge for up payloads.

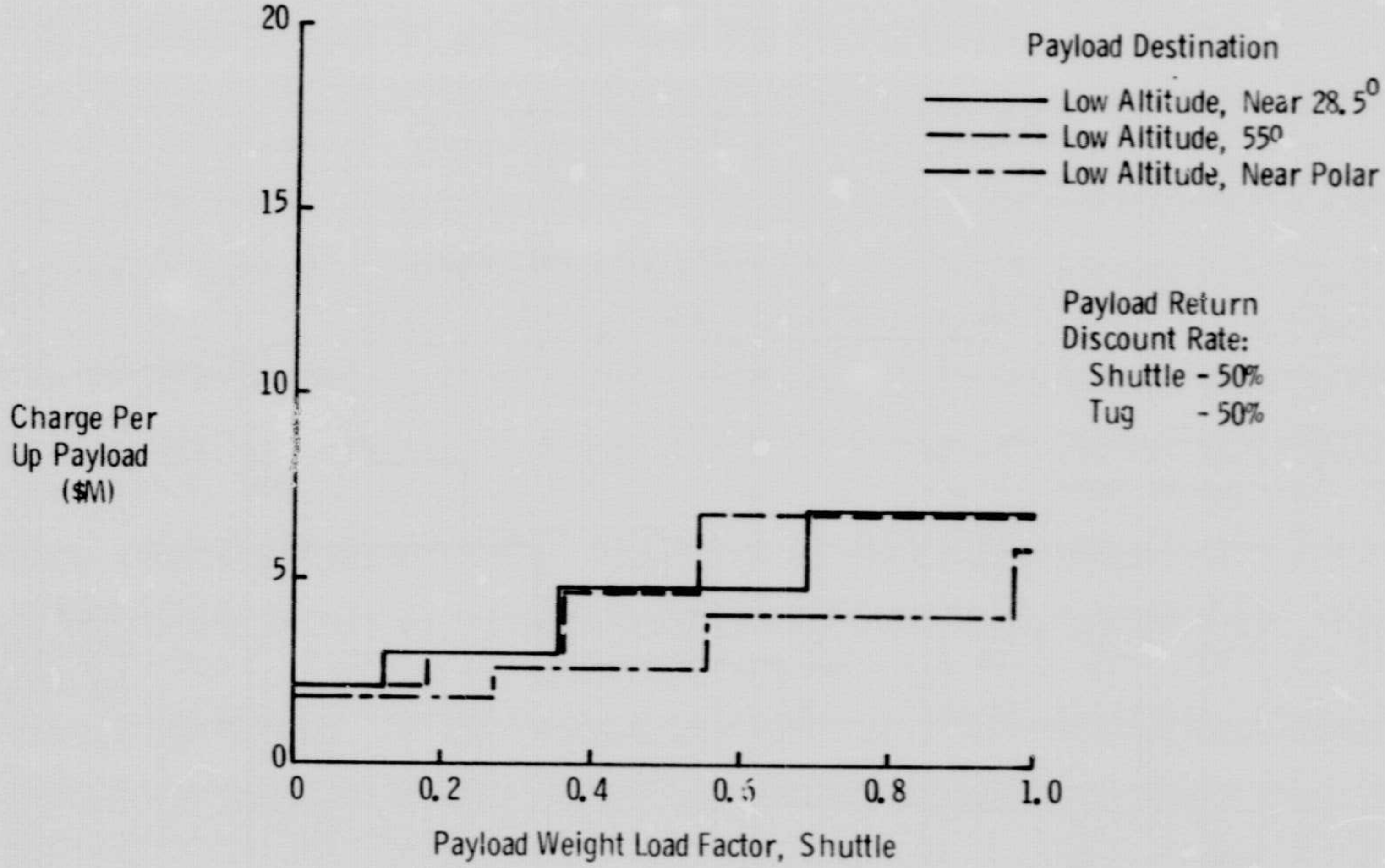


Figure 4-2. Transportation Charge Per Up Payload Trip, Shuttle, 1984 Flights, Charges for Payload Size/Weight Class Approach, Low Altitude Orbits

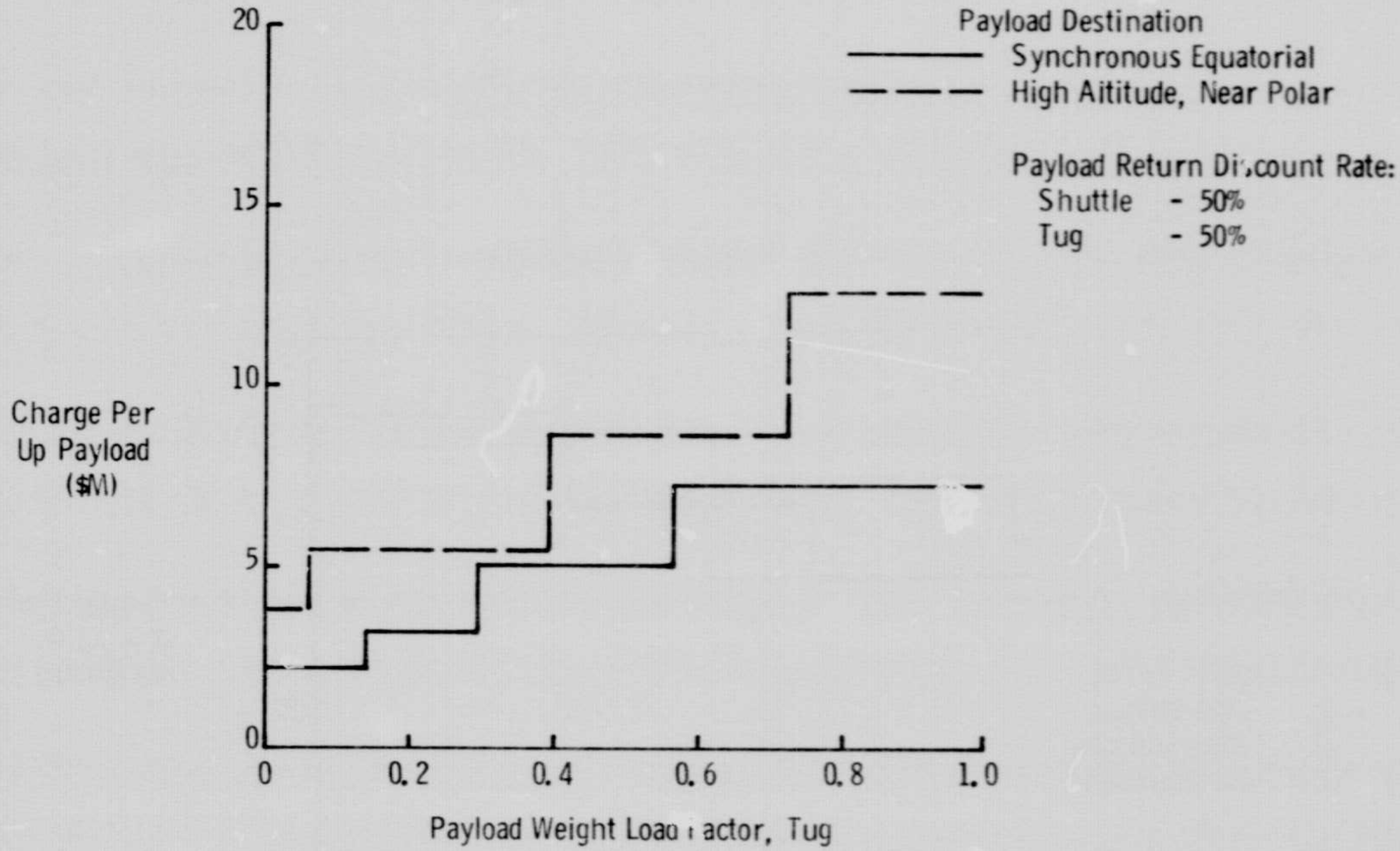


Figure 4-3. Transportation Charge Per Up Payload Trip, Shuttle, 1984 Flights, Charges for Payload Size/Weight Class Approach, High Altitude Orbits

# 5. TRENDS FROM EVALUATION OF CHARGE APPROACHES

The criteria and evaluation techniques discussed in Section 3 were applied to the payload transportation charges resulting from each alternative flight charge approach in order to identify trends and select candidate charge approaches for further consideration. Matricies showing the results of these evaluations in terms of point ratings out of 100 are shown on Tables 5-1 and 5-2. The tables display methods of allocating charges to payloads on the same flight leg for each of the charge approaches considered in the column on the left. Across the top of the matrix the methods of allocating charges between the up flight leg and the down flight leg are displayed. These ratings include all criteria except insensitivity to mission model, which could only be rated for the eight charge approaches considered in the 12-year analysis.

Table 5-1 displays ratings for charge approaches recovering costs for each flight. Comparing the ratings for a 50/50 revenue split for up and down payloads with the rating when no charge is made for the return trip, it is evident that the latter is a more desirable charge approach. However, it was found that some revenue from the down leg is desirable in order to keep the charges for larger payloads reasonable. This led to selection of the 85/15 up/down revenue split for each flight on which a return payload is carried. The latter analysis was run using the payload weight load factor and a method of allocating charges to payloads on the same flight leg. This scheme proved superior to the allocating of charges to up or down flight legs by payload weight load factor or applying rates for down payloads. The superiority of the weight load factor allocation of charges to payloads on the same flight leg with the revenue split between flight legs of 85/15 is evident not only from the high rating (89 points out

Table 5-1. Ratings Against Criteria (In Points Out of 100) Charge Approaches for Recovering Costs for Each Flight (Per-Flight Approaches)

| Allocation of Charges to Payloads On Same Flight Leg by Payload | Allocations of Charges to Flight Legs (Up/Down Splits) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Revenue Split | | | By Payload Weight | By Payload Weight Load Factor | Δ Energy | Payload Trip | Discount Charge Rates for Down Payloads by: | |
| | 100/0 | 50/50 | 85/15 | | | | | Shuttle 50% Tug 0% | Shuttle 50% Tug 50% |
| Unit | 84.5<br>83.9 (1) | 74.7 | | | | | 58.8 | | |
| Weight | | | | 80.3 | | | | | |
| Weight Load Factor | | | 89* | | 81.6<br>73.7 (2) | | | 79.6 | |
| Volume | | | | | 74.3 | | | | |
| Length | | | | | 75 | | | | |
| ΔPropellant | | | | | 78 | | | | |
| ΔEnergy | | | | | | 81.4 | | | |
| Cube Rule Weight Load Factor | | | | | | | | | 81.7 |

(1) 50/50 Revenue Split on Tug
(2) Tug Transported Free by Shuttle

* Acceptable for all Criteria

of 100), but also from the fact that this approach is rated as satisfactory against each of the six criteria being considered at this point in the analysis. This led to giving further consideration to this charge approach and its evaluation against the 12-year mission model.

Table 5-2 displays the same type of matrix for the cargo charge approaches. This matrix shows that splitting the revenue recovered between the up and down flight legs is not desirable for cargo charge approaches. The application of discount rates for down payloads proved to be more satisfactory. The bottom two rows of the matrix display the ratings for the composite charge approach. These ratings are superior to those obtained in the rest of the matrix except for the payload size/weight class. As noted in the footnote, cases were found for both these approaches which had acceptable readings for each of the six criteria being considered at this stage of the analysis.

The results of the 12-year analysis obtained for the eight charge approaches selected are shown in Table 5-3. The top three charge approaches shown recover the costs by making an average charge for each STS flight and splitting the charges between the payloads on that flight. The last five charge approaches in Table 5-3 recover transportation costs by charging payloads as "cargo." The first seven charge approaches shown recover the costs over each five-year period of Shuttle operation. The last charge approach recovers costs over each year of Shuttle operation. The ratings are shown in Table 5-3 in terms of satisfactory, unsatisfactory, and marginal. Satisfactory designates that the rating meets or exceeds the acceptable lower bound. Unsatisfactory means that the rating is below the lower bound and another approach would be preferred. Marginal means that the rating is unsatisfactory but may be rated as satisfactory if some adjustments were made either in the mission model capture or method of applying the charge approach. The reason for marginal rates are given in footnotes and more study is needed.

Table 5-2. Charge Approaches for Recovering Costs In One Year or Five Years (Cargo Charge Approaches, No Charge Ceiling)

| Allocation Of Charges To Payloads On Same Flight Leg By Payload | Allocations of Charges to Flight Legs (Up/Down Splits) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Revenue Split | | | By Payload Weight Load Factor | Discount for Down Payload Charges (%) Shuttle/Tug | | | | | | | |
| | 100/0 | 85/15 | 50/50 | | 0/0 | 50/0 | 50/25 | 50/50 | 70/25 | 70/0 | 70/50 | 88/88 |
| Unit | 77 | | 63.2 | | | | | | | | | |
| Wt. Load Factor | | 69.5 -77(2) | | 77.4 | 77.4 | | | | | | | |
| Volume | | | | 68.7 | | | | | | | | |
| Length | | | | 68.5 | | | | | | | | |
| Size/Weight Class (5 Destinations) | 80.5 | 79.5 | 68.5 | | | 78.2 | 79.8 | 80.9* | | | | |
| Cube Rule Weight (5 Destinations) | | | | | 73.3 | | | 77.7 | | | | 81.5 |
| Cube Rule Wt. L.F. (5 Destinations) | | 75.5 | | | | | | | | | | 76.2 |
| ΔEnergy | | | | | 71.9 | | | | | | | |
| Unit/Wt. L. F. Composite App. (1) | | | | | | 80.7+ -85.5* | | | 84.2 | 81.2 | 82.2 | |
| Unit/Cube Rule Wt. L.F. Composite Approach(1) | | | | | | 82.5+ -85.5* | | | 83.8 | | | |

(1) Discounts for sharing payloads and minimum charge varied.
(2) Varied minimum charge.
\+ Varied shared payload discount.
* Acceptable for all criteria.

Table 5-3. Evaluation of Charge Approaches Against Criteria 1980-1991 (12-Year) User Charge Analysis

| Cost Recov. Period | Charge Approach | Discounts, % | | | Point Ratings | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Shared Trip Shu/Tug | Return Trip Shuttle | Return Trip Tug | Recov. Costs | Payload Effects | High Load Factor | Insen-sitive | Fair Share | Com-petitive | Simple | Total |
| Five Yr → | Per-Flt, $/Wt L.F. | N.A. | (2) | (2) | S | S | S | M(5) | S | S | S | M |
| | Per-Flt, $/Wt L.F. | N.A. | 50 | 0 | S | U | U | M(5) | S | S | S | U |
| | Per-Flt, $/Cube Rule Wt L.F. | N.A. | 50 | 0 | S | U | U | M(5) | S | S | S | U |
| Five Yr → | Cargo, $/Wt L.F. (1) | 20/10 | 60 | 25 | S | M(4) | S | M(6) | S | S | S | M |
| | Cargo, $/Cube Rule Wt L.F. (1) | 20/10 | 60 | 25 | S | M(4) | S | M(6) | S | S | S | M |
| | Cargo, $/Wt L.F. (1) | 30/30 | 50 | 0 | S | U | S | M(6) | S | S | S | U |
| | Cargo, $/Wt L.F. (3) | 30/30 | 50 | 0 | S | U | U | M(6) | S | S | S | U |
| One Year | Cargo, $/Cube Rule Wt L.F. (1) | 20/10 | 50 | 25 | S | U | S | U | S | U | S | U |

(1) $4M Minimum Charge per Payload
(2) 15% of Revenue on Return Trip
(3) $3M Minimum Charge per Payload
(4) Tug Payload Retrieval Charge Unsatisfactory in 1984, Satisfactory 1985 and After
(5) May not Compete with Expendables, Needs More Study
(6) Shuttle + Expendable Upper Stages, 1980-1984 May Lose Payloads to T-III D/Centaur, Needs More Study

Note:

S = Satisfactory

U = Unsatisfactory

M = Marginal, Needs More Study

For the 12-year analysis, the criterion "insensitive to mission model" was rated for the first time. This was made possible by the inclusion of the 1972 mission model in the analysis. Seven of the eight ratings were marginal. The 1972 NASA mission model uses expendable upper stages to launch payloads in the first five years prior to obtaining the full-capability Tug. Delta and Agena stages were used in the capture as well as Centaur stages. The transportation charges for the Shuttle/Delta and Shuttle/Agena combinations exceeded the transportation charges for comparable expendable launch vehicles with the ground rules used in this analysis. Further study of this is needed to establish the cost comparison on a firmer basis. The expendable launch vehicle costs should be evaluated as well as the expendable upper stage costs per flight. The capture analysis should also be redone with multiple payload launches on the expendable upper stages for the STS, replacing the single payload launches on expendable Deltas, and in some cases Agenas, in order to obtain more competitive transportation charges.

The last case analyzed with launch costs recovered over each year proved to have an unsatisfactory rating in the areas of payload effects, sensitivity to mission model, and competitive with expendable launch vehicles. The cost per flight was too high in the early years (1980-1982), which resulted in these unsatisfactory ratings.

# 6. OBSERVATIONS AND RECOMMENDATIONS

The STS User Charge Analysis progressed from the initial quick-look phase, where the objective was to eliminate low-ranking charge approaches and develop the rationale for their elimination; through the charge approach uprating phase, where the objective was to develop charge approaches which could meet the criteria and become candidates for the final phase of the analysis which tested the charge approaches against the 12-year mission model. As the study progressed through these phases, observations were made and rationale was developed for the elimination of certain of the charge approaches. This section summarizes these observations and rationale.

1. The Shuttle should charge the upper stage for Shuttle transportation. Charging the upper stage for Shuttle transportation results in fair cost sharing to the user; for instance, when an upper stage shares a Shuttle flight with a low-altitude payload, the upper stage pays a fair share of the Shuttle transportation cost.

2. A charge should be made for payload return, i.e., free payload return on either the Tug or Shuttle should be eliminated. The return charge revenue is needed to recover transportation costs and still remain competitive with expendable launch vehicles for the up flight.

3. The transportation charge rate for returning the down payload should be low. The analysis shows that only with a low charge rate for down payloads can payload return and reuse be sufficiently competitive with the launching of a new payload to encourage payload return. Further, payload return is required in order to develop high STS load factors, i.e., empty Shuttle return flights represent inefficient (deadhead) STS operation. It is desirable that the average spacecraft residual value be very much greater than the cost of return transportation.

4. The magnitude of the reduction in rate for payload return will probably differ for the Shuttle charge for return payload transportation and for the Tug charge for return payload transportation. The analysis to date shows that return payload charge discounts of 40 to 60 percent for composite cargo charge approaches for the Shuttle are sufficient to attract payload return for reuse and yet recover sufficient revenue for down payloads. The corresponding discount for Tug payloads will probably be lower in order to ensure recovery of STS costs.

5. The simpler cargo charge approaches failed to satisfy the criteria.

   a. Simple payload length, or volume, or weight is not as desirable a basis for payload transportation charges as is payload load factor. Simple charges in terms of unit length, or unit volume, or unit weight do not adequately consider changes in launch vehicle performance with payload destination. The simple schemes do not pass the fair share test nor do they result in payload transportation charges which are competitive with expendable launch vehicles.

   b. Simple charge approaches such as unit charges for payload transportation or charges per payload trip are not as desirable as other approaches. The simple charges cannot meet the fair share criterion since heavier payloads transported to the same destination are charged the same as lighter payloads, and the mission model contains a wide variety of payload weights.

   c. Charging for upper stage payload transportation by the propellant increment required to transport that payload can be eliminated. The charges resulting from this approach are very similar to those resulting from the payload weight load factor approach which is a much simpler charge approach and therefore preferred.

d. The concept of charging the payload for Shuttle transportation in proportion to the energy added to the payload, which was studied as one of the cargo charge approaches, is less desirable than charging by the payload weight load factor. The launch azimuth effects on STS performance are only partially accounted for using the energy-added approach. Polar payloads do not pay their fair share relative to low inclination payloads.

e. Tug transportation charge for payloads in proportion of energy added to the payload is less desirable than the weight load factor approach. If two payloads weigh the same, and one is put into an escape orbit and one goes to synchronous equatorial orbit, the energies are approximately the same, however, more is demanded of the launch vehicle in putting the payload into synchronous equatorial orbit than on a escape trajectory. The primary reason for this is the performance required of the launch vehicle to make the plane change for synchronous equatorial orbit for which the energy method does not account.

f. Ceiling for transportation charges is undesirable in the view of the NASA Administrator. The study was directed to delete further consideration.

6. It was also concluded that a composite cargo charge approach combining the best features of the simpler cargo charge approaches could be made to satisfy the criteria. The composite cargo charge approach combined a unit charge (minimum payload transportation charge) with a charge proportional to payload load factor and incentives built in by reducing transportation costs for returning payloads and payloads sharing the same flight leg. Parametric studies of this composite charge approach showed that:

   a. Increasing the minimum payload charge from $2M to $4M decreases the maximum charge for large payloads significantly.

   b. Substituting the cube rule weight load factor approach for the straight weight load factor approach increases the average Shuttle load factor resulting in lower charge rates. The

cube rule weight load factor approach also protects the STS operator from low revenue per flight on high-volume, low-density payloads.

d. A potential problem for the STS operator with the composite cargo charge approach as formulated in this report is revealed if one considers a user with a large payload who choses to fly a light, dummy payload along with the large payload and claim a sharing discount. The sharing discount can exceed the added cost for the sharing payload if the sharing payload discount rate was on the order of 20 percent or larger. This so-called "dummy" payload problem can be eliminated by reformulating the composite cargo charge approach. Further study on this is recommended.

7. The payload size/weight class charge approach is a recommended alternate to the composite cargo charge approach. The analysis showed that the size/weight class charge approach has a satisfactory rating against the criteria although its total point rating is lower than the total point rating for the composite cargo charge approach.

8. A four- or five-year initial breakeven period for recovery of STS costs is recommended.

9. The upper stage charge policy needs further study to insure that, with expendable upper stages, the STS will be competitive with expendable launch vehicles such as the Titan IIID Centaur and Titan IIIF Centaur.

10. Further consideration should be given to additional charges accounting for (a) Orbiter occupancy time in excess of basic time lines, (b) high-priority flights, (c) use of ancillary equipment, and (d) STS flight crew (above basic complement).

11. Charge approaches recovering costs for each flight are not recommended. In order to meet the criteria, these charge approaches must use the average charge per flight over the first four or five years of Shuttle operation. This fact obviates the potential basic advantage of the approach recovering costs for each flight, since the charge estimate is based on future traffic estimates. In addition, the approach has a deficiency of not allowing the user to project transportation costs since they would depend on the detail makeup of the flight manifest on which his payload is transported.

# 7. FUTURE STUDIES

It is recommended that NASA continue the user charge study retaining the composite cargo charge approach option and the payload size/weight class charge approach option. Primary consideration should be given to the following items in continuation of the study:

1. The sensitivity of the charges to Shuttle costs to be recovered

2. Modifying the composite cargo charge approach to eliminate the potential "dummy" payload problem

3. Improving the composite cargo charge approach as applied to upper stage payloads. An increase in the minimum charge may be desirable, especially for expendable upper stages on the Shuttle. The increased minimum charge for upper stage payloads may make STS payload charges more competitive with expendable launch vehicles. In addition, the cost per launch of the expendable launch vehicles should be re-estimated to establish a firmer base for this criterion.